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EVALUATION OF THREE TECHNIQUES FOR PRODUCING LASER PULSES OF NANOSECOND DURATION

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Air Force Cambridge Research Laboratories
L. G. Hanscom Field, Massachusetts

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Technical Report No. 3
Period 1 July to 31 December 1972

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Three devices, a short-pulse laser, a coaxial Pockel cell shutter, and a single-crystal transmission-line Pockel cell, have been evaluated as techniques for producing laser pulses approximately 1 nsec in duration. The short-pulse laser has produced pulses that range from 0.5 nsec to 2.0 nsec in duration with peak powers from 25 to 300 kW. Pulses 1.8 nsec in duration FWHM (full width at half maximum) with risetime of less than 0.4 nsec have been gated from Q-switched ruby laser pulses by the coaxial shutter, while pulses 1.3 nsec FWHM have been obtained in the same fashion with a transmission-line shutter.

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Abstract

Three devices, a short-pulse laser, a coaxial Pockel cell shutter, and a single-crystal transmission-line Pockel cell, have been evaluated as techniques for producing laser pulses approximately 1 nsec in duration. The short-pulse laser has produced pulses that range from 0.5 nsec to 2.0 nsec in duration with peak powers from 25 to 300 kW. Pulses 1.8 nsec in duration FWHM (full width at half maximum) with risetime of less than 0.4 nsec have been gated from Q-switched ruby laser pulses by the coaxial shutter, while pulses 1.3 nsec FWHM have been obtained in the same fashion with a transmission-line shutter.

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Purpose of Project

The purpose of this research is to gain an understanding of the processes by which laser radiation causes damage to nominally transparent materials, especially those used in the lasers themselves.

Equipment Development

The completion of a facility to perform carefully monitored damage experiments with single, selected, 20-psec duration mode-locked ruby laser pulses, or with 20-nsec duration ruby laser pulses was described in Technical Report No. 1. The results of damage measurements on dielectric mirrors, performed with the above mentioned apparatus, were reported in Technical Report No. 2. In that report it is noted that damage measurements at pulse durations near 1 nsec were needed to test the hypothesis that damage was due to electron avalanche. In this report, the experimental evaluation of three sources capable of producing laser pulses approximately 1 nsec in duration will be described.

Conclusions

A simple transmission-line Pockel cell shutter is capable of producing pulses 1.3 nsec FWHM. Since these pulses are gated from a pulse generated by a TEM_{00}-mode Q-switched ruby laser that is limited to operation in a single longitudinal mode, they will be temporally smooth and possess the special mode properties required for damage measurements.

Evaluation of Three Techniques for Producing Laser Pulses of Nanosecond Duration*

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I. INTRODUCTION

A mode-locked ruby laser system capable of reliably producing single subnanosecond duration pulses with a smooth and radially symmetric energy density profile and sufficient energy to damage dielectric materials in spot sizes larger than 0.1 mm has been developed at Air Force Cambridge Research Laboratories (Bliss and Milam, 1972; Milam, 1971). A Q-switched ruby laser, limited to operation in the TEM_{00} mode and in a single longitudinal mode, has also been assembled as a source of 20-nsec duration pulses with the beam quality necessary for damage measurements. Monitoring apparatus which is used to characterize the pulses from both laser sources in unprecedented detail has been developed, and is described fully in a previous report (Bliss and Milam, 1972).

Using both laser sources, damage has been studied in dielectric mirrors from five fabricators (Bliss, Milam, and Bradbury, 1972; Bliss, Milam, and Bradbury, 1973) at pulse durations of 20 psec and 20 nsec, and as a function of laser spot size at the 20-nsec duration. The time of occurrence of mirror breakup

* This research was supported jointly by the Air Force and the Advanced Research Projects Agency of the Department of Defense.

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and plasma formation relative to the arrival of a damaging 20-psec pulse at the mirror has been studied.

Single-shot damage thresholds ranged from 0.6 to 2.9 J/cm^2 at 20 psec and from 20 to 60 J/cm^2 at 20 nsec. Two sets of mirrors appear to damage as a result of linear absorption, and all of the mirrors show scattered, small, absorption damage, frequently extending through many dielectric layers. Except for the two sets, the remainder of the mirrors appear to damage as a result of electron avalanche at sites free from absorbing defects.

If electron avalanche is the causative mechanism, the damage threshold in J/cm^2 is expected to decrease as the duration of the damaging laser pulse is decreased (Bliss, 1970), until the pulse duration is reduced below some not yet specified value Δt. For pulse durations below Δt, the energy threshold is expected to be approximately constant. The current mirror damage data predicts that the transition should occur at $\Delta t \cong 0.8$ to 1.0 nsec. A measurement of the threshold for laser-induced gas breakdown as a function of pulse duration has produced similar results (Wang and Davis, 1971).

To continue the investigation of pulse duration dependence of laser damage, damage measurements at pulse duration near 1.0 nsec have been planned. This report will discuss an evaluation of several schemes that allow production of pulses approximately 1.0 nsec in duration.

2. EVALUATION OF TECHNIQUES FOR PRODUCING NANOSECOND DURATION LASER PULSES

2.1 Possible Sources of Short Duration Pulses

Ruby laser pulses 8 to 10 nsec in duration are readily produced by passive Q-switching techniques, and pulses of approximately 4 nsec are possible with cavity dumping schemes (Vuylsteke, 1963).

For the case of cavity dumping, the pulse duration has a minimum value set by the cavity length. It is conceivable that the pulse duration of cavity-dumped lasers could be reduced to 2 nsec, but the resulting cavity would have an optical length of 30 cm, and would allow TEM_{oo}-mode diameters of only 0.5 to 0.7 mm.

Single mode-locked ruby laser pulses, selected from a mode-locked train, typically have durations on the order of 5 to 50 psec (Mack, 1968). Intracavity etalons have been used to narrow the lasing bandwidth in mode-locked Nd: YAG lasers thereby stretching the pulse width to 200 psec (McMahon, 1972), and a grating tuned Nd: glass laser has produced pulses 0.3 nsec in duration (Magnante, 1969). The prospect for production of single mode-locked pulses with durations of 1 nsec is limited, and the general difficulty of obtaining reliable operation in mode-locked solid state lasers encourages a search for other techniques.

Fast Pockel cells shutters (Michon, Guillet, LeGoff, and Raymond, 1969) have been rather successful in producing short pulses, with pulse widths as short as 0.7 nsec being reported (Alcock and Richardson, 1970). The data published in that particular case shows what is apparently severe electronic ringing resulting in the production of a sequence of pulses.

Finally, a modified cavity dumping scheme capable of producing pulses with continuously variable and precisely controllable durations on the order of 1 nsec has been reported (Szoke, Goldhar, Grieneisen, and Kurnit, 1972). This technique looks very attractive for it requires only a fast rise (or fall) time of the switching mechanism to generate a symmetrical output pulse.

This report will present data on the new cavity dumping scheme, and on two types of Pockel cell shutters, all of which have been considered as sources for laser pulses usable in damage measurements.

2.2 The "Szoke Short-Pulse Laser"

2.2.1 DESCRIPTION OF THE LASER

The short-pulse laser (SPL) described by Szoke et al (Szoke, Goldhar, Grieneisen, and Kurnit, 1972) consists of a Q-switched laser in which one end mirror is replaced by a Michelson interferometer as depicted in Figure 1. A phase switch, capable of rapidly impressing 180 degree phase shifts on the radiation entering the interferometer, or an amplitude switch capable of abruptly terminating the interferometer input field, is also included in the cavity. The oscillator is operated in the standard Q-switched mode. When the lasing field in the cavity has increased to the desired intensity, the phase or amplitude switch is fired producing a short pulse of predetermined duration at the interferometer output.

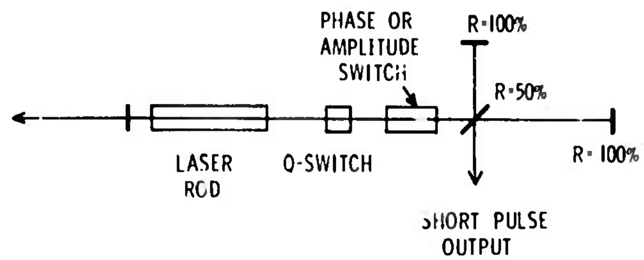

Figure 1. Diagram of Short-Pulse Laser Proposed by Szoke et al (Szoke, Goldhar, Grieneisen, and Kurnit, 1972)

In order to understand the SPL, consider the operation of a passive Michelson interferometer shown in Figure 2. If the input E_i is a plane wave of amplitude A and frequency ω

$$Ei = Ae^{i\omega t}, \tag{1}$$

there will be reflected and output waves E_r and E_o given by

$$E_r = A(R^2 e^{i\omega t} + T^2 e^{i\omega(t-t')}), \tag{2}$$

and

$$E_o = RTA\,(e^{i\omega t} - e^{i\omega(t-t')}). \tag{3}$$

Here R and T describe the interferometer beam splitter, and t' gives the relative time separation between the waves arising in the two interferometer arms of length ℓ_1 and ℓ_2. Therefore,

$$R^2 + T^2 = 1, \tag{4}$$

and

$$t' = \frac{2}{c}(\ell_2 - \ell_1) = 2(t_2 - t_1), \tag{5}$$

where c is the speed of light.

If the path length difference in the interferometer is adjusted so that $\omega t' = 2m\pi$, m = 0, 1, ... integer, $E_o = 0$ and all radiation entering the interferometer is returned along the input direction. If, while this condition holds, the input to the interferometer is suddenly terminated at the splitter, then after a time $2t_1$ one of the two fields necessary for cancellation of the interferometer output will have become zero. Radiation will continue from the longer arm resulting in the emission of a pulse of duration t' and amplitude RTA. The output pulse duration is determined by the difference t' in the transit times of the interferometer arms, and the pulse intensity is at most 1/4 of that initially stored in the interferometer. It should also be noted that a pulse is emitted by the interferometer if it is initially empty, and then filled by an abruptly rising waveform. The response time of the pulse terminator sets the

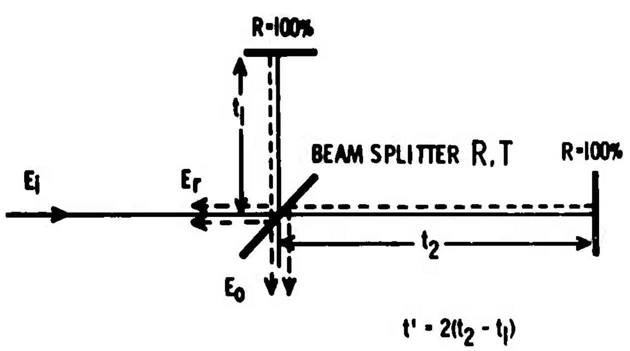

Figure 2. Michelson Interferometer

minimum achievable pulse duration while the coherence length of the input field or problems associated with physical mode mismatch determine the upper limit in pulse duration.

If the input field is terminated in a time long compared with the expected pulse duration t', the interferometer output will be given by

$$
\begin{aligned}
E_o(t) &= RTA \left\{ E_i(t) - E_i\,(t - t') \right\} \\
&= RTA \left\{ E_i\,(t - t') + t' \frac{dE_i\,(t - t')}{dt} + \ldots - E_i\,(t - t') \right\} \\
&= RTA \left\{ t' \frac{dE_i\,(t - t')}{dt} \right\}.
\end{aligned} \tag{6}
$$

In this derivative mode, the output from the interferometer is largely determined by the temporal variation in the input field.

If the interferometer is incorporated into a Q-switched laser as shown in Figure 1, there will be some output from the interferometer during the buildup of the Q-switched pulse, even if the interferometer spacing has been adjusted to achieve minimum output. The coupling during pulse buildup is a simple manifestation of the derivative mode of operation, and can be controlled to a large extent by simply selecting the temporal profile for the Q-switched pulse which achieves the desired output from the interferometer. This mode of operation allows for the possibility of tailoring pulses to consist of a slowly rising, relatively low intensity ramp followed by a short duration, intense pulse. Pulses of this shape have frequently been discussed for use in generating laser-induced plasmas.

Finally, it is noted that if a π phase shift is suddenly impressed on the cw field filling the interferometer, a pulse equal in intensity to the input field will be emitted by the interferometer. This is readily apparent from Eqs. (2) and (3). If the phase shift is accomplished in a time short relative to t', a single pulse of duration t' will be obtained. Phase shifts of magnitude $2m\pi$ during the time t' will result in a sequence of 2m pulses, one m occurring in the time interval commencing after the shorter arm has filled with phase shifted radiation, and the second m occurring as the phase shifted radiation drains out of the longer arm. Note that the emission of a pulse via this phase shift technique results in a "hole" in the reflected field E_r, but that the field E_r is otherwise preserved intact. This will be important in understanding the operation of a demonstration laser to be described in Section 2.2.2.

The elementary description given here suffices to describe the principles on which the laser is based. It does not, of course, adequately describe the dynamics

of an oscillator incorporating an interferometer, and realization of the full potential of the scheme proposed by Szoke will depend upon obtaining an adequate analysis. This is being pursued as time permits.

Three techniques have been studied for achieving the rapid phase or amplitude switching necessary for production of pulses with subnanosecond durations: (1) absorption of the pulse in laser-induced, intracavity sparks, (2) pulse termination by fast intracavity Pockel cell shutters, and (3) pulsed electro-optic phase shifters. The results obtained in each case are discussed in the following three sections.

2.2.2 SHORT-PULSE LASER WITH TERMINATION BY INTRACAVITY BREAKDOWN

Most attractive of the three schemes, because of its simplicity, was pulse termination by laser-induced sparks. For this case, the amplitude switch is simply a pair of lenses mounted in an appropriate gas or liquid cell.

Laser-induced sparks have been the subject of hundreds of papers. Termination of intense laser pulses by these sparks has been suggested (Tomlinson, 1964), and many of the properties of a laser beam that has been transmitted through a spark have been studied (Bobin, Canto, Floux, Guyot, Reuss, and Veyrie, 1968; Alcock, DeMichelis, and Richardson, 1970; Young, Hercher, and Chang-Yiu Wu, 1966; Meyerand and Haught, 1964; and Tomlinson, 1964). The list of references is intended to be indicative of the general work done in the field; for a complete bibliography, excellent review articles are available (DeMichelis, 1969, 1970).

Despite the bulk of papers, we were unable to find detail measurements, on a nanosecond time scale, of the fall time of pulses terminated by sparks. In order to decide which of the readily available dielectrics furnished the most rapid fall times, pulse fall time measurements were made for sparks in several liquids, gases, and in optical quality glass.

A diagram of the apparatus used for these measurements is shown in Figure 3. A passively Q-switched, TEM_{oo}-mode ruby laser, limited to operation in a single longitudinal mode is used as a source of pulses. These pulses have a smooth temporal profile and a peak power of approximately 0.5 MW. The pulses are amplified as required by a single pass through an amplifier with an active length of 15 cm. After amplification, the spatial profile is elliptical but radially smooth. The beam is brought to a focus by one lens, recollimated by a second, and after suitable attenuation is incident on a fast photodiode. The only measurement performed is to record the temporal profile of the transmitted pulse as a function of the parameters of the breakdown medium.

Several general conclusions can be drawn concerning the data: (1) Sparks could not be produced in liquids without producing beam breakup prior to laser-induced breakdown. This was true for water, ethyl and methyl alcohol, and solutions of Q-switched dyes such as DDI in methanol.

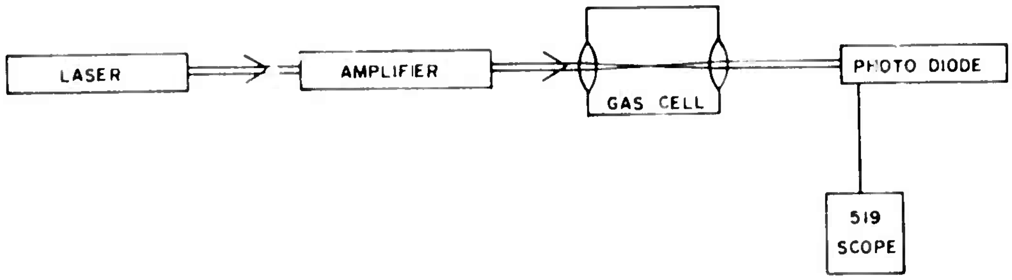

Figure 3. Apparatus for Measuring Fall Time of Laser Pulses Terminated by Laser-Induced Sparks

(2) Internal breakdown in optical glass produces faster pulse termination and is more reproducible than termination by sparks on either the front or rear surface. The most rapid fall times observed were on the order of 1.5 nsec, and the transmitted intensity after breakdown was typically 10 to 20 percent of that at breakdown. No evidence of beam degradation prior to breakdown was observed. Examples of pulse termination by internal breakdown in glass are shown in Figure 4.

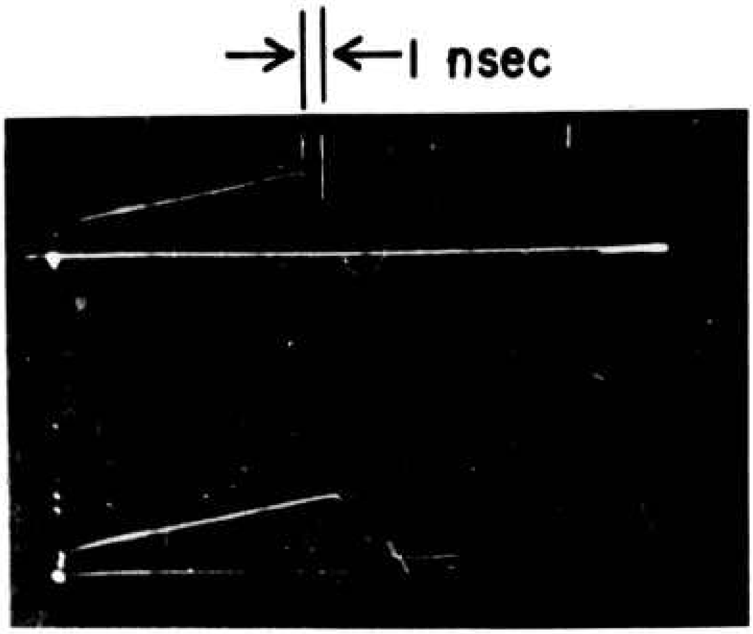

Figure 4. Pulses Terminated by Absorption in Self-Induced Sparks in Glass

(3) The fall time of pulses terminated by sparks in gases such as helium, argon, nitrogen, air, and SF_6 can be less than the fall time resulting from termination by sparks in glass, provided that the transmitted beam is apertured to reject small-angle scatter. Pulse termination by sparks in helium at various pressures is shown in Figure 5. Helium was somewhat unique in that short duration plasmas could be formed at low gas pressures as shown in Figures 5a and 5b. The termination shown in Figure 5c, for helium at 150 psi, is similar to that of all other gases observed. There are small differences in the pulse fall times and attenuation obtained with different gases, and the data is being reduced to guide any further efforts to improve the pulse fall time.

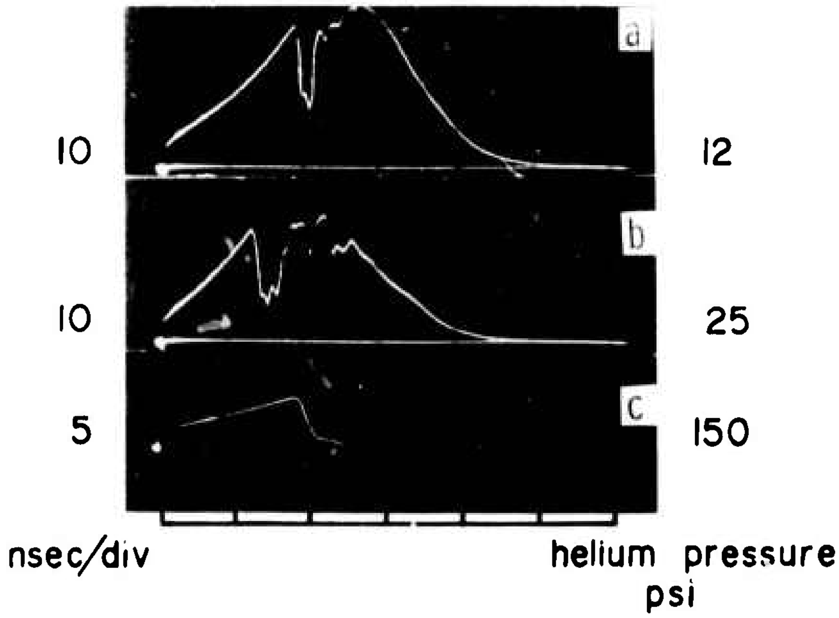

Figure 5. Pulse Termination by Self-Induced Sparks in Helium at Different Pressures

A digitization of the waveform resulting from spark termination in helium at 150 psi is compared with the detector response in Figure 6. The detector response is obtained by monitoring 20 psec duration pulses from a mode-locked ruby laser.

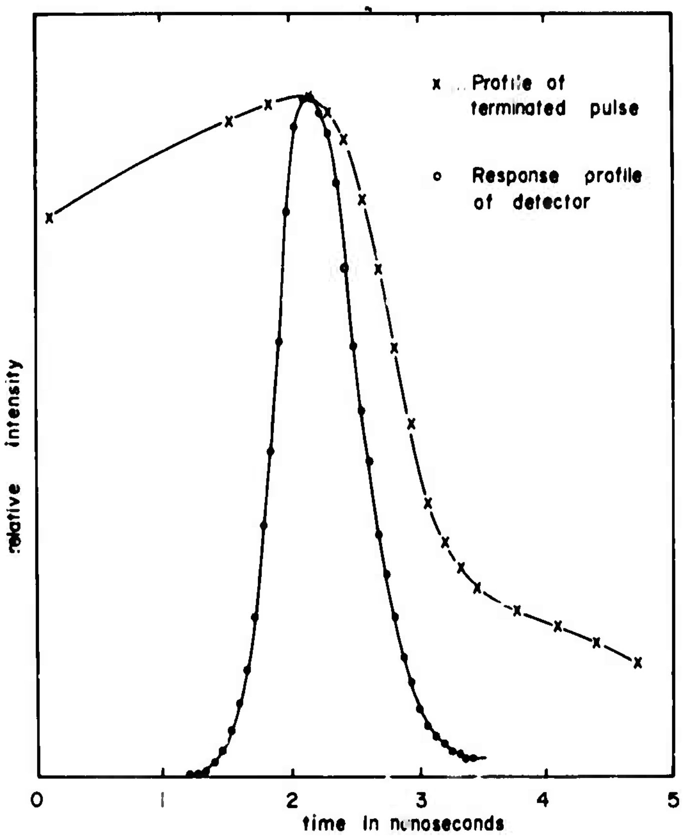

Figure 6. Comparison of the Detector Response Profile with the Fall Time Due to Pulse Termination by Self-Induced Sparks in Helium at 150 psi

The lens pair was incorporated into a short-pulse laser as shown in Figure 7. Data obtained with this laser is illustrated in Figure 8, for the case in which helium is used as the breakdown medium. The waveforms result from simultaneously displaying both the normal output of the Q-switched laser and the pulse emitted by the interferometer, which has been delayed, on the same oscilloscope trace. The Q-switched output is attenuated by 50 percent relative to the short pulse. At an intensity determined by the spot size at the waist of the 5-cm lenses and by the helium pressure,

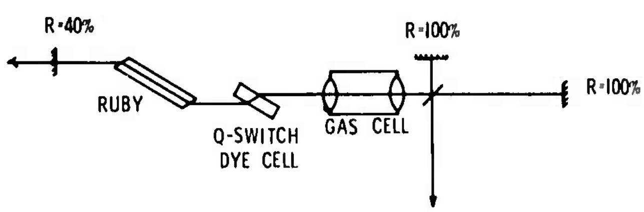

Figure 7. Szoke Short-Pulse Laser Switched by Internal Gas Breakdown

breakdown occurs. The fall time observed in this case is complicated by the fact that a pulse, equal in intensity to the pulse in the interferometer output, is returned to the laser cavity where it appears on the Q-switched output after having been attenuated to some extent by the breakdown plasma.

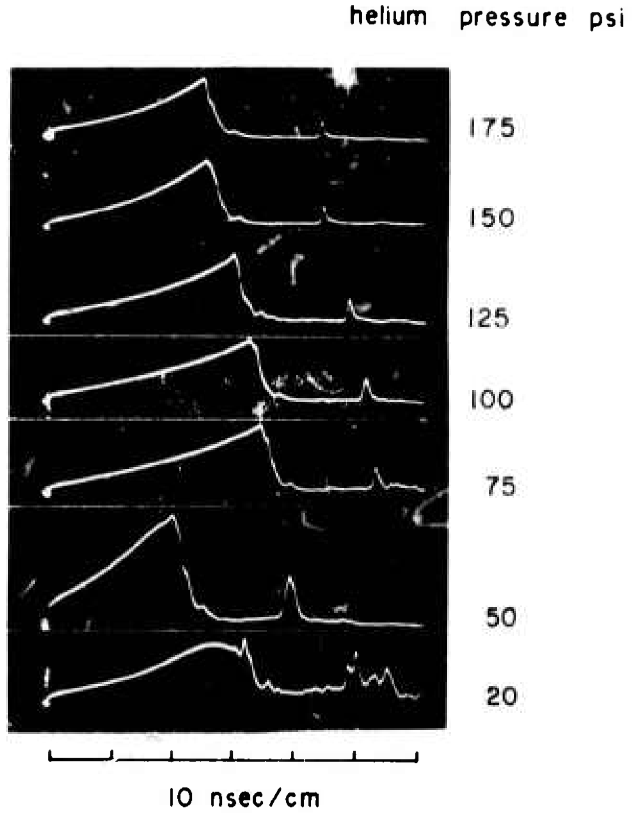

Figure 8. Short Pulses Produced by Intracavity Pulse Termination in Laser-Induced Sparks. On each trace, the terminated, Q-switched pulse and the resulting short pulse emitted by the interferometer are displayed

As the helium pressure is decreased, the threshold for breakdown increases, resulting in termination later on the profile. Internal scope delay of approximately 25 nsec was introduced so that the 20 and 50 psi profiles would be properly displayed, and for the 20 psi profile the normal output has been attenuated by an additional 50 percent relative to the short pulse.

In all cases, termination is sufficiently slow so that the output of the interferometer is a derivative of the fall time. At the higher helium pressures, the pulse has a duration of 1 nsec FWHM whereas a width of 0.5 nsec is predicted by the path length difference of 15 cm. Peak intensity in the interferometer output is about 50 kW at 20 psi, and approximately 25 kW at 175 psi due to the lower intensity stored in the cavity at the time of switching.

2.2.3 SHORT-PULSE LASER WITH PULSED PHASE SHIFTER

A short-pulse laser containing an intracavity, pulsed phase shifter has been assembled, as shown in Figure 9. The phase shifter consists of a KDP crystal mounted between thin copper foil leads. The crystal is 5 mm by 50 mm, and the calculated phase shift voltage is 1910 V if the entire length of the crystal is driven. Since 6 kV pulses from the laser-triggered spark gap shown in Figure 23 were available, only a 16-mm section of the crystal was driven.

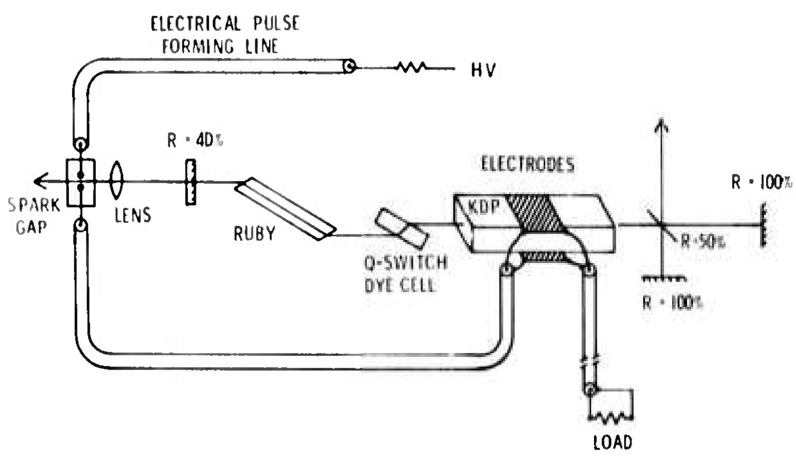

Figure 9. Short-Pulse Laser with Pulsed Intracavity Phase Shifter

No attempt was made to measure the time response or the magnitude of the phase shift in the crystal because of the difficulty of measuring them on a nanosecond time scale.

Output pulses from the interferometer, produced by pulsing the phase shifter after a Q-switched pulse has built up in the cavity, are shown in Figure 10. It will be noted that one obtains not only the expected single pulse, but also a pair of pulses, and later some additional pulses with less well defined shape. The first single pulse is the expected response of the interferometer to the phase shift of the

input field, and is produced at the cost of leaving a "hole" in the radiation field circulating in the oscillator. When this "hole" returns to the interferometer, two additional pulses are produced, one from the front edge of the hole, and one from the rear edge of the hole, since the interferometer will emit pulses in response to either rapid increases or decreases in the amplitude of the input field. The emission of this pair of pulses produces a larger hole in the cavity, which returns to produce additional output from the interferometer.

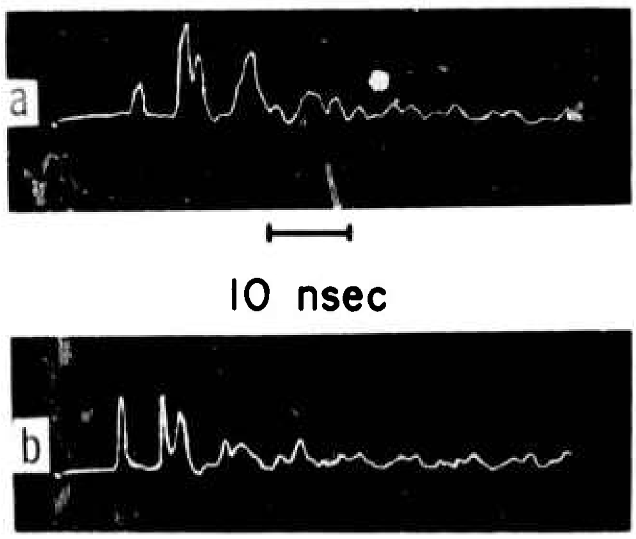

Figure 10. Interferometer Output Obtained by Firing the Pulsed Phase Shifter in the Short-Pulse Laser Cavity Shown in Figure 9.

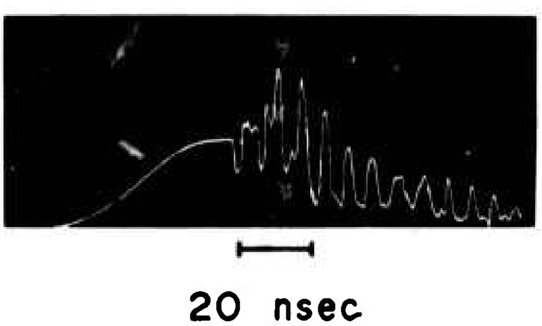

Figure 11. Perturbation of the Normal Q-Switched Output Due to Pulsing the Phase Modulator of the Laser Shown in Figure 9

The perturbation of the field inside the oscillator is shown in Figure 11, where a fraction of the normal Q-switched output is displayed.

Although this mode of operation is not fully understood, several features are apparent. The phase modulator is only 30 to 40 percent efficient in gating radiation from the cavity, as shown by the depth of the hole in the waveform of Figure 11, but its response is sufficiently fast

that the widths of the primary pulses agree well with the expected pulse widths, 1.3 nsec for Figure 10a and 0.5 nsec for Figure 10b. The short pulses are rigorously timed relative to the firing of the spark gap, and may therefore be separated from subsequent pulses by a Pockel cell shutter driven by a short pulse. This is a sharp contrast to the situation in passively mode-locked lasers, in which the position of the output pulses is not precisely known. Since the phase shifter is constructed as a transmission line, the voltage pulse used to drive the phase shifter could also be used to drive the shutter.

The relative amplitude of the primary and subsequent pulses is partially dependent on when, relative to the peak of the Q-switched pulse, the phase switch is fired. If the switch was fired early, subsequent pulses were larger because they were switched out closer to the peak of the Q-switched pulse.

The reason for the abrupt increase in the amplitude of the Q-switched output following emission of the pulses is not fully understood. Since the reflection maxima from a Michelson interferometer are broad spectrally, the laser automatically selects a lasing wavelength for which the interferometer is a good reflector. This means that the two waves returning from the interferometer are in phase during pulse buildup, which makes it difficult to understand the increased amplitude of the wave returning from the interferometer.

It is currently thought that the increased amplitude may be due to spatial hole-burning effects in the ruby rod. The Q-switch field, being a single longitudinal mode, depletes the inversion at the antinodes of the field distribution of the mode. When the wave returning from the interferometer is suddently shifted in phase, it is able to feed on inversion not available to the original field. If this is the cause, it should be possible to see an increase in the output of a normal Q-switched laser simply by pulsing an intracavity phase shifter after the intracavity optical field has reached peak intensity.

2.2.4 SHORT-PULSE LASER WITH INTRACAVITY ELECTROOPTIC SHUTTER

A laser has been assembled using the coaxial Pockel cell shutter, described in Section 2.3.2, as an intracavity pulse terminator. The device can be operated in two modes. The Pockel cell is energized by a voltage pulse from the spark gap, and rotates the plane of polarization of the incident radiation by 90°. A polarizing prism can be placed after the Pockel cell, so that the input to the interferometer is actually terminated as shown in Figure 12a, or the field with rotated polarization can simply be allowed to fill the interferometer as shown in Figure 12b. For a period of time equal to the total transit time difference t' of the interferometer, orthogonally polarized fields will appear at the interferometer output thereby

preventing destructive interference. The two components in the output can be separated with a polarizing prism.

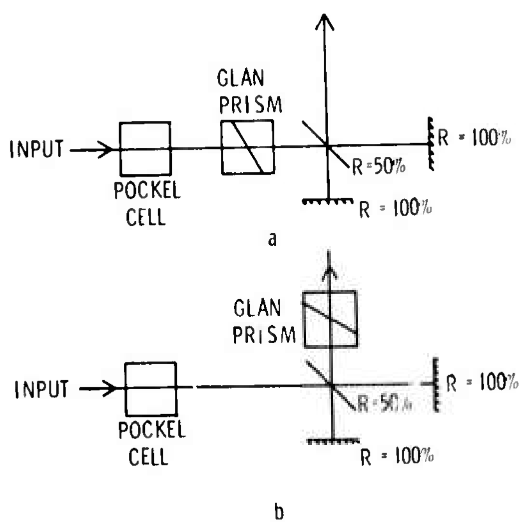

Figure 12. Two Configurations for Achieving Short Pulses by Means of an Intracavity Pockel Cell. In (a) the polarization of the input field is rotated so that it is blocked by the prism, thereby terminating the input and producing a pulse in the interferometer output. In (b) the rotated field enters the interferometer, and a short pulse is emitted due to the existence of orthogonally polarized fields in the interferometer output

Both modes have been demonstrated, but the folding mirror in the Pockel cell was damaged before a significant body of data was accumulated. An example of a short pulse produced in the configuration of Figure 12b is shown in Figure 13.

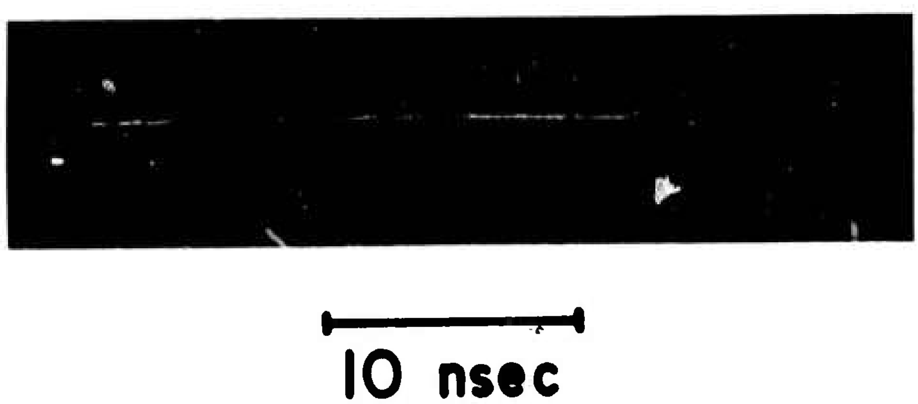

Figure 13. Short Pulse Resulting from Intracavity Polarization Rotation, Using the System Shown in Figure 12a. The interferometer leakage during the buildup of the Q-switched pulse is approximately one half as intense as the short pulse itself in this instance

2.3 Pockel Cell Shutters

2.3.1 INTRODUCTION

Fast response, transmission-line shutters have been widely used since they were first described (Michon, Guillet, LeGoff, and Raymond, 1969). A typical transmission-line Pockel cell contains 2 C-axis cut KDP crystals which are in series optically, but in parallel electronically as shown in Figure 14. Fast response is expected because the KDP is used as the dielectric in a short section of stripline which can be fabricated to closely match the impedance of the driving source and furthermore, the use of two crystals reduces the halfwave voltage by 50 percent. The most undesirable feature of the double-crystal cell is the large optical insertion loss, which cannot be avoided in high power laser beams by the use of antireflection coatings since a technique for depositing hard, damage-resistant, antireflection coatings on KDP has not been found.

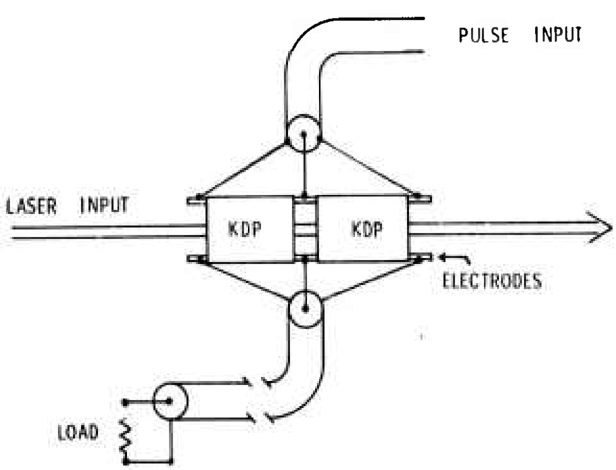

Figure 14. Double-Crystal, Transmission-Line Pockel Cell

It has been noted (Milam, 1972) that the input and exit faces of KDP crystals can be cut at Brewster's angle thereby eliminating reflection loss at the expense of introducing dispersion and beam deflection since one Brewster face must be rotated 90° relative to the other. In shutters for use with beams up to 1.5 cm in diameter, loss at the two inner surfaces could be eliminated by fabricating both "crystals" from a single element as shown in Figure 15. A split central electrode could be fitted around a neck turned on the crystal, or the crystal could be a round cylinder with three bands for electrodes. Because of the poor optical quality of

large KDP crystals, there is a limit to the size achievable in this design for a given length-to-aperture ratio.

Since the large insertion loss of the transmission-line shutter is primarily due to reflection, it is desirable to evaluate the performance of single-crystal designs. We have studied two types of Pockel cell driving circuits. The first, a completely coaxial design, is discussed in some detail since, to the authors' knowledge, it is a configuration which has not previously been considered. The second, a very simple single-crystal transmission line cell, will be discussed briefly in Section 2.3.3.

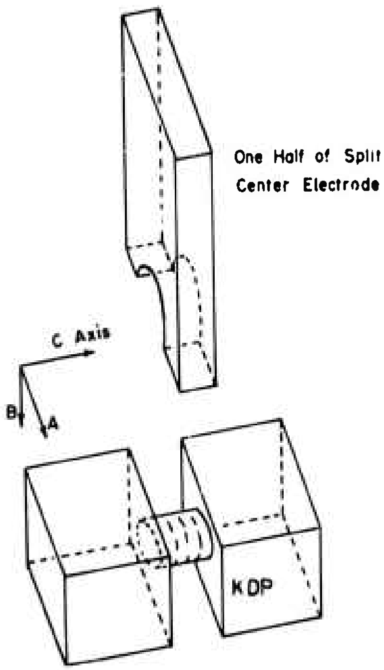

Figure 15. Double-Crystal KDP Element Fabricated from a Single Crystal to Reduce Reflection Loss

2.3.2 COAXIAL POCKEL CELL DESIGN

A laser-triggered Pockel cell shutter, complete with driving electronics, is shown schematically in Figure 16. The horizontally polarized input beam is transmitted by the first polarizing prism and the Pockel cell, deflected by the second prism, and focused into the laser-triggered spark gap. When the spark gap is fired, a voltage pulse of magnitude V/2 and duration 2t is delivered to the Pockel cell, which responds by rotating the polarization of the laser beam so that it is transmitted through the second prism for the duration of the voltage pulse. Here V is the potential stored on the pulse forming line, and t the time required for electrical signals to travel the length of the line.

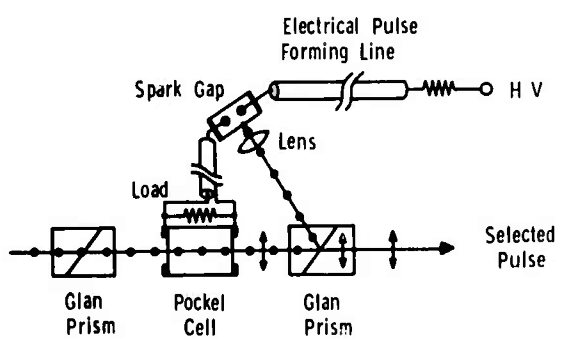

Figure 16. Pockel Cell Shutter and Electronic Pulse Generating Circuitry

While the high-pressure spark gaps are capable of producing kilovolt pulses with subnanosecond risetimes, the shutter response will be degraded by the capacitance and inductance of the cell.

An example of severe degradation of an applied voltage pulse is shown in Figure 17. The lower waveform is the voltage measured at the end of a terminated line with the Pockel cell disconnected. The top waveform shows the portion of a ruby laser pulse gated through the shutter when the Pockel cell is reconnected. The breakup in the gated pulse is caused by ringing due to inductance of the long wires used to connect the line to the cell.

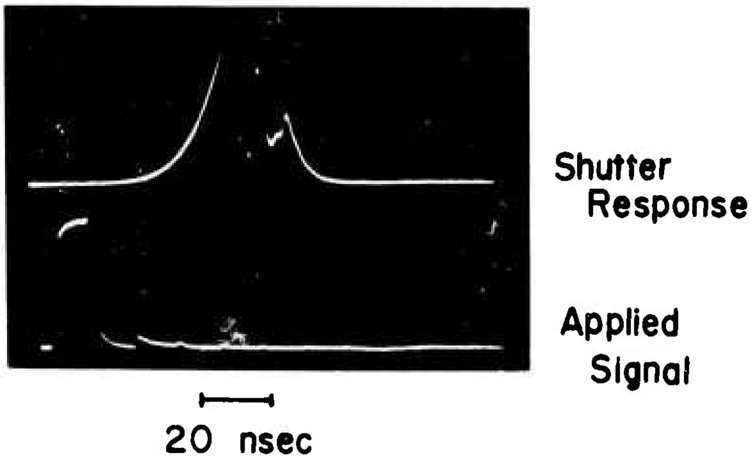

Figure 17. Degradation of Pockel Cell Shutter Response Due to Lead Inductance

A completely coaxial shutter shown in Figure 18 has been suggested by one of the authors (CCG) as a technique for achieving minimum lead inductance. The pulse-forming line, spark gap, KDP housing, and the terminating load are all contained in a single tube filled with high pressure N_2. Three separate interior assemblies, each of different diameter, allow the unit to be operated with a characteristic impedance of 10, 25, or 50 ohms for checking the effect of line impedance on risetime.

The laser beam enters the unit along the axis, and is deflected to one side after it has passed through the KDP crystal. Entrance and exit windows are oriented at Brewsters angle. After being rejected at the second polarizing prism, the beam is used to trigger the spark gap.

The electrode gap is adjustable over a range of 0 to 5 mm, and is set to yield the desired self-breakdown voltage at the chosen gas pressure.

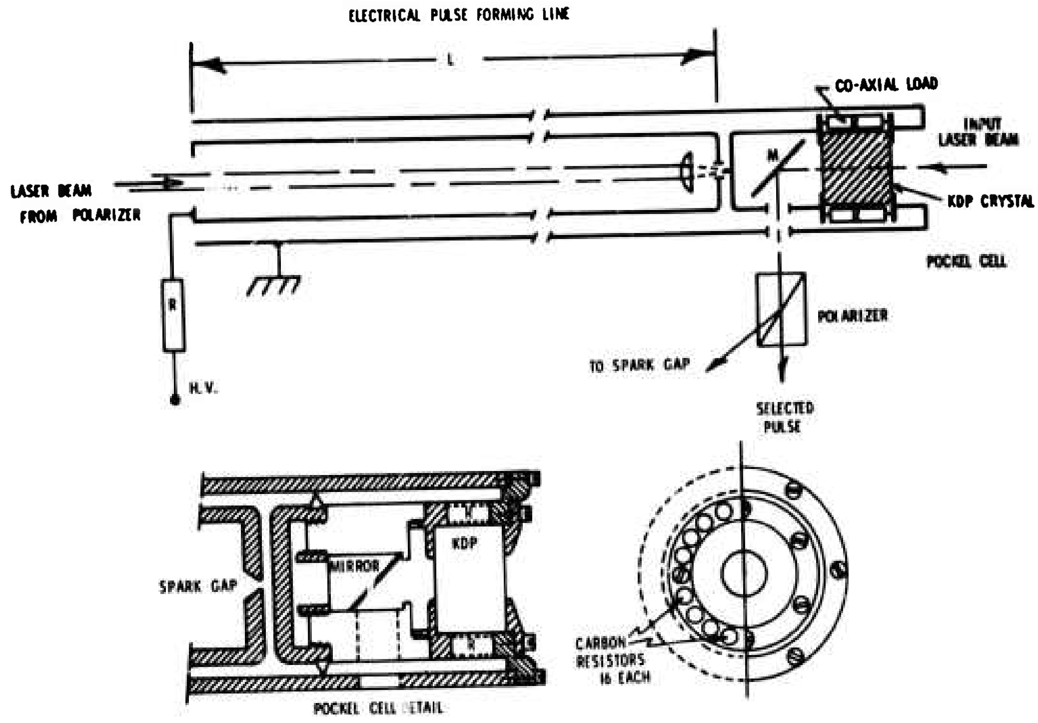

Figure 18. Coaxial Pockel Cell Shutter

Some general observations can be made concerning the performance of this unit:

(1) The stored voltage required to achieve complete gating is over 25 kV in the 10-ohm unit instead of the 12 kV expected on the basis of the 6 kV dc halfwave voltage of the KD*P crystal. Stored voltages of approximately 20 kV are required with the 25- and 50-ohm units. It is currently thought that a significant voltage drop is maintained across the spark discharge itself.

(2) As expected, the rise and fall time of the shutter depend heavily on the gas pressure and composition. Pressure dependence of the shutter profile with a 10-ohm line is illustrated in Figure 19. In each instance the stored voltage was 16 kV. The sequence was produced by successively decreasing the gap spacing in steps of 0.25 mm. At each gap spacing, the N_2 pressure was adjusted so that the shutter was triggered near the peak of the incident ruby laser pulse. As a result of this procedure, each trace shown in Figure 19 is the record of a separate experiment. The apparent progression of the firing time toward the early portion of the laser pulse is not directly related to the changes in pressure. Pulses produced at a given pressure, during this set of experiments, were very reproducible in both shape and amplitude. Examples of the pulses are shown in

Figure 20. Based on the detector response profile, these pulses are calculated to be 1.85 nsec in duration FWHM. This is approximately 1.6 times the expected value since the pulse forming line was 17.5 cm in length ($2T \cong 1.16$ nsec).

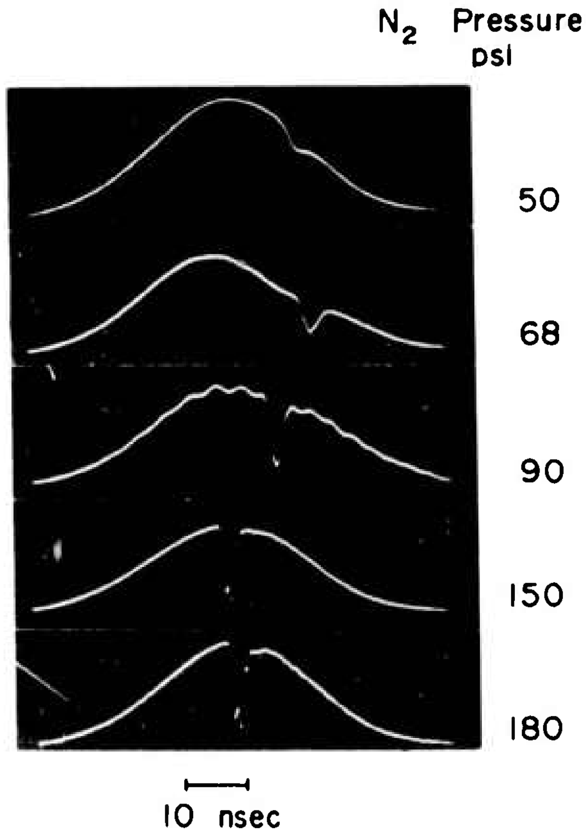

Figure 19. Temporal Response of the Coaxial Shutter as a Function of Pressure

(3) The displayed pulses from the 10-ohm unit have a 10 to 90 percent risetime of 0.4 nsec, and good fall time at 250 psi, but the trailing edges of the pulses produced with the 25-ohm and 50-ohm units shown in Figure 21 are severely degraded.

The primary objection to the design is the necessity of folding the incident laser beam. A modification, in which the coaxial hard line is replaced by a bundle of flexible cables, is being fabricated to overcome this problem.

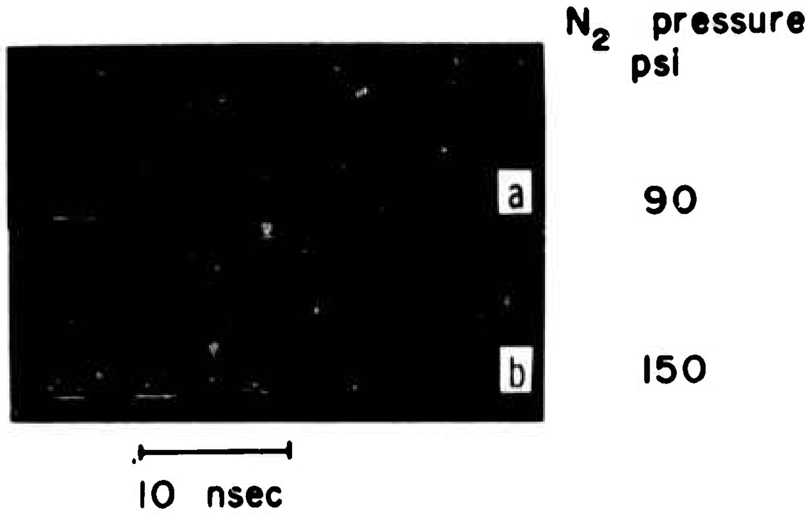

Figure 20. Optical Pulses Produced by the Coaxial Shutter

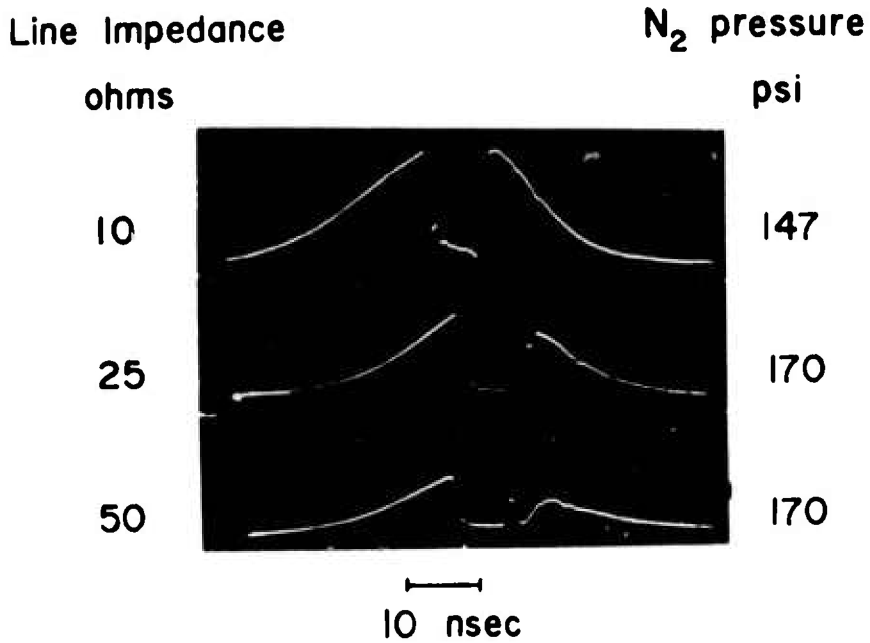

Figure 21. Shutter Profiles of the Coaxial Unit at Characteristic Impedance Levels of 10, 25, and 50 Ohms

2.3.3 SINGLE-CRYSTAL, 50-OHM, TRANSMISSION-LINE SHUTTER

A very simple shutter has been assembled as shown in Figure 22. The high voltage pulse is applied to the ends of the crystal by thin foil electrodes. A 90 percent deuterated KD*P crystal, 2 cm by 2 cm by 2.5 cm in size, oriented so that the C axis lies along the long dimension, is used. The optical aperture in the foil electrodes is 1.2 cm in diameter. The beam enters and exits through Brewster-angle windows that are rotated relative to each other by 90° so that the light transmitted by the shutter experiences minimum loss.

The cell is driven by pulses produced by the spark gap shown in Figure 23. Sections of RG-8 cable are used for the pulse forming and transmission lines. The voltage pulse is terminated by a 50-ohm load after propagating for approximately 15 nsec beyond the crystal.

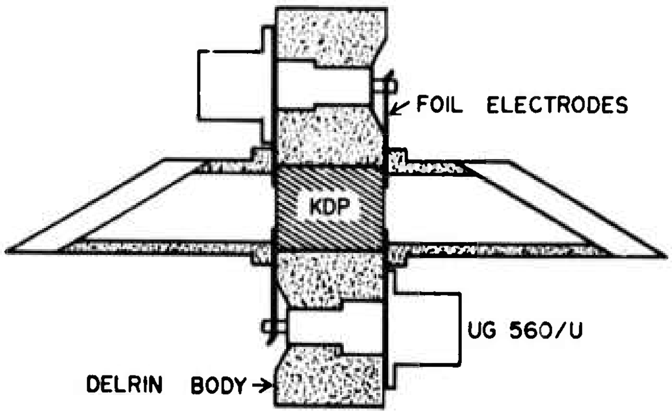

Figure 22. Single-Crystal Transmission-Line Pockel Cell. Windows, both shown aligned for the same polarization, are rotated 90° relative to each other

The output pulse is shown in Figure 24 with N_2 fill pressures of 175 to 200 psi in the spark gap, and 18 kV stored on the pulse forming line. When allowance is made for detector rise time, the computed pulse width is 1.3 nsec FWHM. Most of the structure on the base line is electronic pick-up thought to be due to the manner in which the cable connectors are attached to the Pockel cell. The pulse shown in the lower trace of Figure 24 was obtained by removing a 6.0-dB filter from the detector set to display pulses as seen in the upper trace. The structure on the baseline is unaffected except for a single pulse 7 nsec after the primary pulse which is off-scale. The secondary is an optical pulse, about 1/20 as intense as the gated pulse, generated by electrical transients on the transmission line.

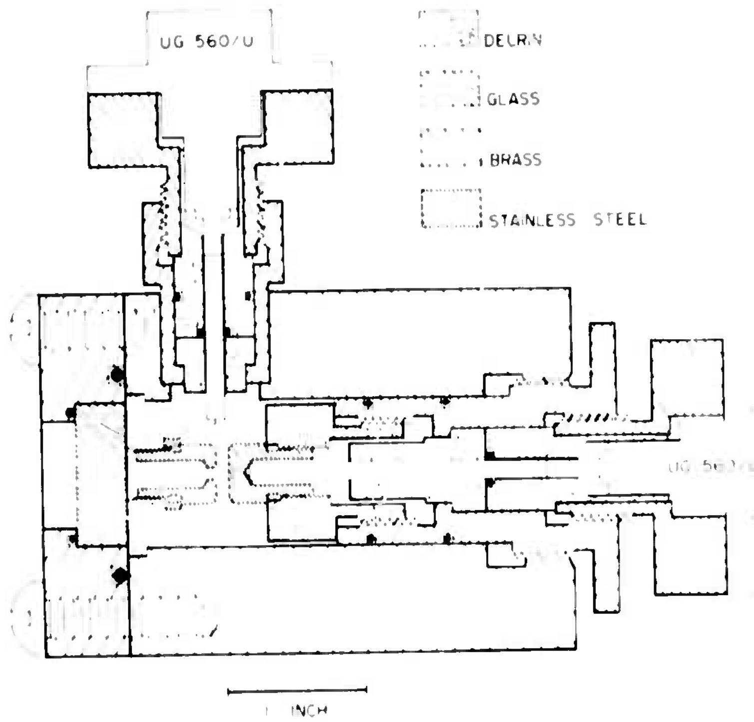

Figure 23. Laser-Triggered Spark Gap

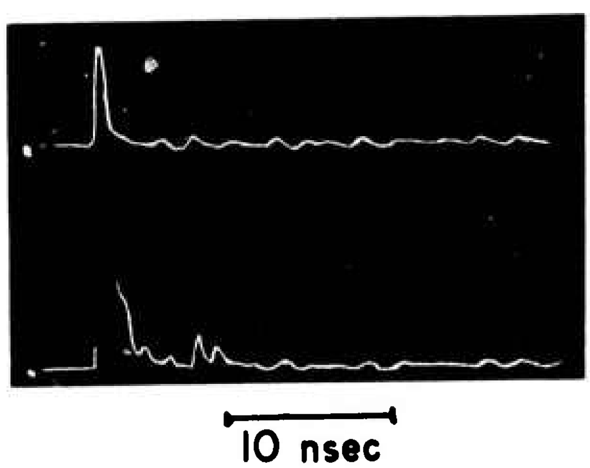

Figure 24. Pulses 1.3 nsec in Duration Produced by the Single-Crystal Transmission-Line Shutter

Since this pulse waveform is excellent for the damage experiments proposed at 1-nsec durations, no effort was made to eliminate the secondary pulse as it should cause no problems in damage studies.

3. CONCLUSIONS

At the moment, the system capable of easily producing nanosecond duration pulses is the 50-ohm shutter discussed in Section 2. 3. 2. The damage apparatus will be reassembled with this system and damage measurements will commence shortly.

The Szoke short pulse laser has yielded interesting results with a minimum of effort, and should develop rapidly into a versatile and usable system. Development work on this laser and the coaxial Pockel cell design will continue as an effort parallel to the damage work.

Acknowledgments

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